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PVF2 Transducers for NDE

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Abstract
We report on recent calculations and experiments on the broadband properties and impulse characteristics of PVF2 transducers and arrays. Experimental wedge transducers show bandwidths of approximately 100% in the excitation of surface acoustic waves at 7 MHz on nonpiezoelectric silicon nitride ceramic substrates. Computer calculations predict similar bandwidths for interdigital transducer arrays on PVF2 films for surface acoustic wave excitation on similar substrates. Insertion loss versus frequency measurements on bulk longitudinal wave transducers in water at frequencies in the 1 to 30 MHz range show good agreement with theory. A computer program for multilayer piezoelectric films predicts included angles of acceptance exceeding 60°, and control of acceptance angle profiles, in face plates using multilayer PVF2 films.

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PVF_2 TRANSDUCERS FOR NDE

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ABSTRACT

We report on recent calculations and experiments on the broadband properties and impulse characteristics of PVF_2 transducers and arrays. Experimental wedge transducers show bandwidths of approximately 100% in the excitation of surface acoustic waves at 7 MHz on nonpiezoelectric silicon nitride ceramic substrates. Computer calculations predict similar bandwidths for interdigital transducer arrays on PVF_2 films for surface acoustic wave excitation on similar substrates. Insertion loss versus frequency measurements on bulk longitudinal wave transducers in water at frequencies in the 1 to 30 MHz range show good agreement with theory. A computer program for multilayer piezoelectric films predicts included angles of acceptance exceeding 60°, and control of acceptance angle profiles, in face plates using multilayer PVF_2 films.

PVF_2 bulk wave transducers are made by bonding 25 μ PVF_2 film (≈ 1/2" × 1/2") onto brass backing rods with V-6 epoxy. The PVF_2 film is obtained from Kureha Corporation in stretched, poled and electroded form. We etch off the aluminum electrodes, which erode quickly when placed in water, and put down a thin layer of chrome followed by a layer of gold (≃ 1000 Å).

These bulk wave transducers have a very flat frequency spectrum up to 20 MHz when radiating into water.[1] This is expected, since the acoustic impedance and velocity of longitudinal waves in PVF_2 (3.83×10^5 gm/cm^{2}sec and 2.15×10^5 cm/sec, respectively) match relatively well to the impedance and velocity of water (1.48×10^5 gm/cm^{2}sec and 1.48×10^5 cm/sec). As the impedance mismatch at the brass/PVF_2 interface is large, little energy is radiated into the brass. These characteristics of PVF_2 result in a clean, nearly bipolar impulse response (Fig. 1). PVF_2 transducers have shown a 60 dB two-way insertion loss at their resonance frequency ($\lambda = 4 \times$ film thickness).

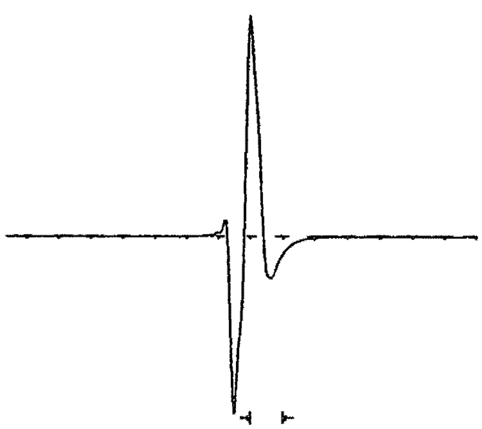


Fig. 1. Impulse response of a broadband PVF_2 transducer.

Although the piezoelectric coupling coefficients of PVF_2 are low compared to PZT, the power output of a PVF_2 transducer remains linear with higher applied voltage than PZT. We have carried out power measurements at higher frequencies (13.56 MHz). The power output of a PVF_2 transducer remained linear up to 750 volts (3×10^5 v/cm), the limit of the signal generator. It is expected that the power-voltage relation will remain linear above 3×10^5 volt/cm. Calculations have shown that PVF_2 can produce approximately 5 times the power/volume that PZT can produce.[2]

Multilayer transducers also have been investigated. By folding and bonding an electroded film, PVF_2 transducers can be operated with high applied RF electric fields without requiring high voltage. This provides a multilayer transducer in which the voltages of the individual layers are in parallel while their acoustic fields are in series. This also provides a way of obtaining lower resonant frequencies with a given film thickness. Multilayer transducers have been constructed and used to observe the movement of the mitral valve of the human heart (see Figs. 2 and 3).

We are currently examining the possibility of a PVF_2 face plate which could receive acoustic radiation at angles other than normal incidence. For a face plate used as a receiver, broadband frequency response leads to broad angular response.[3] Therefore a PVF_2 face plate should have a very broad angular response. Just as a wide aperture optical lens has better resolution than a narrow aperture lens, a broad angular response transducer will lead to better resolution than a transducer with a relatively narrow angular response. Thus, a PVF_2 face plate promises good resolution. Photolithography would be used to produce periodic electrode patterns on the PVF_2 surface which could then be electronically scanned to achieve imaging. At present, theoretical studies on the angular response of brass backed PVF_2 face plates are underway using a computer program developed by Auld and Roberts.[3] Figure 4 shows the voltage response as a function of angle of a PVF_2 brass backed film. The three curves show the effect of the value of the piezoelectric coupling coefficient e_{zx} transducer response. (Shear wave effects have been suppressed in order to simplify understanding of the result.) As e_{zx} and e_{zz} have opposite signs, it is seen that e_{zx} detracts from the uniform character of the voltage response from 0° to 30°.

Calculations have also been made which involve both shear and longitudinal waves. These show a large shear wave resonance near a 55° angle of incidence. The tail of these resonances contributes to the uniform character of the response from 0° to 30°.

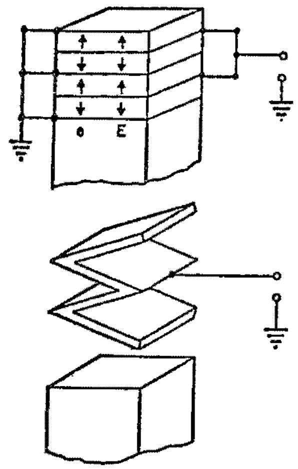


Fig. 2. Multilayer transducer structure.

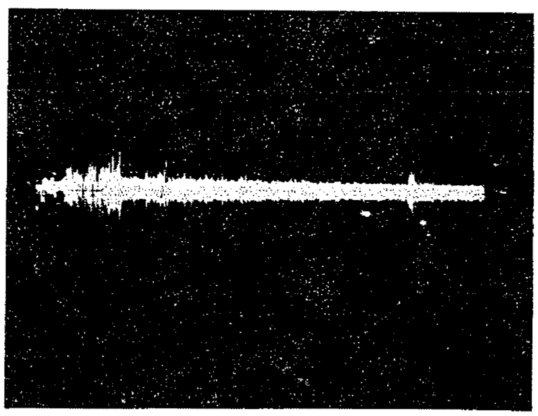


Fig. 3. Photo shows an echo from a mitral valve leaflet. The right-hand pulse is the mitral valve echo; the near-in signals are echoes from inhomogeneities in the brass used as the transducer backing.

We have devised a scheme that involves stacking three layers of PVF_2 in such a way that the resulting e_{zx} and e_{zz} of the stacked films have the same sign. By rotating a film 90° about an axis perpendicular to the plane of the film we can interchange e_{zx} and e_{zy}, which differ by a factor ≈ 5. By inverting a film we change the sign of e_{zx} and e_{zz}. Using these changes, we theoretically construct a three-layer stack with the properties shown on Fig. 5. This figure also shows the voltage response of such a stack. The theoretical response of such a stack is more favorable (out to 45°) than a single film.

Wedge transducers have been constructed for the excitation of surface acoustic waves on high velocity nonpiezoelectric substrates. These could be used to perform NDE on surface flaws. In this case, a PVF_2 transducer irradiates the substrate at an angle such as to phase match with a surface acoustic wave propagating on the substrate. The experimental wedge transducers have a resilent RTV wedge between the PVF_2 transducer and the surface wave substrate allowing experimental variation of the wedge angle by distorting the RTV, this being a critical parameter.[4] (See Fig. 6). As PVF_2 can be used at frequencies near 20 MHz, the wavelength of such a surface wave will be small, and resolution will be good. Using 30 μ PVF_2 films, a bandwidth of approximately 100% has been observed at 7 MHz in initial measurements using two identical wedge transducers on a silicon nitride substrate.

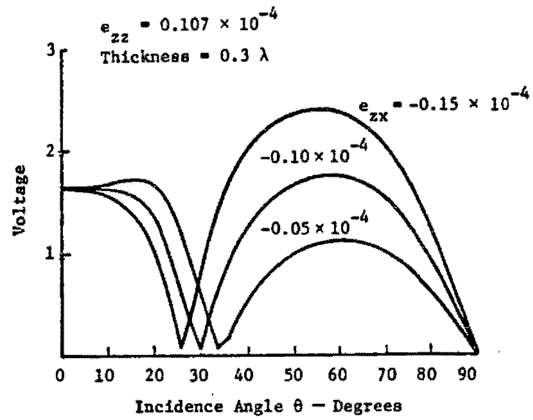


Fig. 4. Theoretical PVF_2 face plate response.

		e_{zx}	e_{zz}	Thickness λ
Layer 1	--	-1.0	+1.07	0.07
Layer 2	--	0.2	-1.07	0.07
Layer 3	--	0.2	-1.07	0.07

$Q_s = 5$

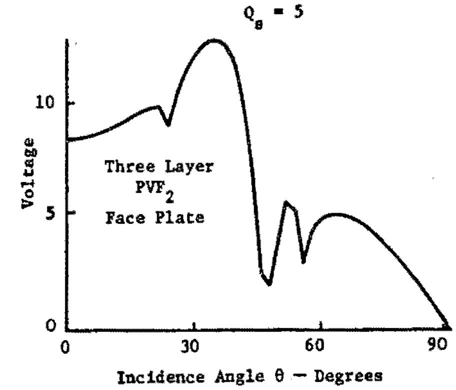


Fig. 5. Theoretical PVF_2 face plate response.

Interdigital surface wave transducers in which PVF_2 film provides coupling between the interdigital array (deposited on the PVF_2) and a nonpiezoelectric substrate are being studied. The effective coupling is determined by evaluating the fractional difference in velocity $(\Delta v/v)$ of a surface wave propagating in the film substrate combination under two conditions: (1) no electrodes are present at the surface which is to contain the interdigital array, and (2) a uniform conductor is placed at that surface. The surface wave velocities have been calculated using a computer program developed by Kino and Wagers,[5] are shown in Fig. 7. Focusing on the curve label 10-00, we see that this curve rises to a reasonably high value (0.8%) and is also fairly broad. This implies that an IDT with the 10-00 structure would be capable of a broad frequency response. The resulting transducer will be flexible and mechanically conformable for use on curved surfaces (see Fig. 8).

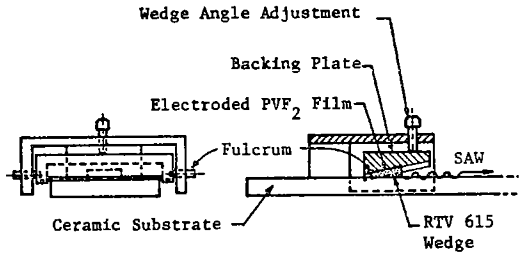
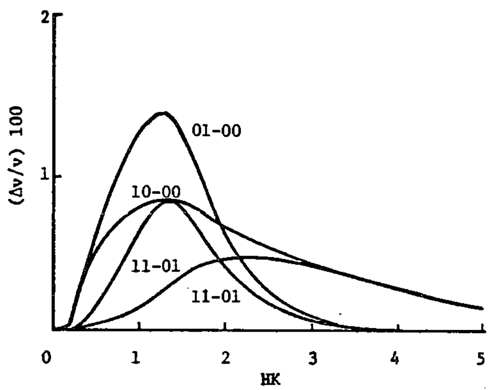


Fig. 6. Wedge transducer schematic.



Cases

01-00 - IDT on top of PVF_2
short at sub-PVF_2 interface
10-00 - IDT at PVF_2 sub-interface
short on top of PVF_2
11-01 - IDT at sub-PVF_2 interface
11-10 - IDT on top of PVF_2
(H = film thickness, K = propagation constant)

Fig. 7. $\Delta v/v$ versus film thickness.

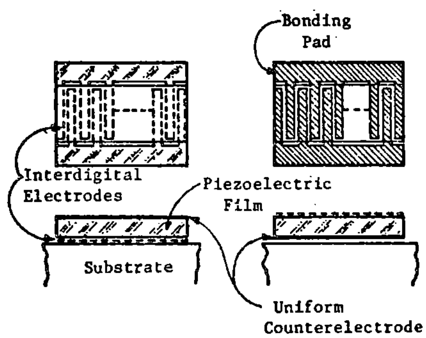


Fig. 8. IDT schematic.

The PVF_2 program at Stanford also includes a material synthesis group. C. Frank and S. Bowker of the Chemical Engineering Department are studying the chemistry and synthesis of PVF_2, aimed at improving the piezoelectric properties of PVF_2.

R. Reigelson, R. Route, and R. DeMattei are involved in melt press production of PVF_2 films at the Stanford Center for Materials Research.[2]

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